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New Extended Radio Sources From the NVSS

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Abstract. We report the results of the spectroscopic observations carried out at the SAO RAS 6-m telescope for the optical components of nine new extended radio sources found in the NVSS catalog. The measured redshifts of the host galaxies are in the range of $z = 0.1$–0.4. The physical sizes of radio sources were calculated within the standard cosmological model. The two most extended objects, 0003+1512 and 0422+0351 reach the sizes of 2.1 Mpc and 4.0 Mpc, respectively. This is close to the maximum size of known radio sources.

1. Introduction

The statistics of extended radio sources required for the cosmological tests is currently insufficient. Its expansion is only possible in the region of faint fluxes. The observational foundation of this process are the NVSS (Condon et al., 1998) and FIRST (White et al., 1997) surveys. We investigated the NVSS catalog using the modified programs from Amirkhanian (2009). The result is a list of more than two thousand extended radio source candidates. The redshift of most of them is unknown. In this work we have obtained the optical spectra and determined the redshifts of nine radio sources from this list. Before starting the observations, we have to find the object whose spectrum we expect to study. The identification of extended radio sources is a difficult task, since the probability of a false identification increases together with radio source angular size. The search for the candidates in the radio sources host galaxies was carried out in several stages. Originally, the NED and SDSS databases were searched for the objects (galaxies or quasars), located from the coordinates of the studied radio sources by no more than 30″. Next, we sought for the component of the radio source, closest to the optical object. And if the distance between them was not in excess of 10″, or the optical object was not further than 10″ from the major axis of the radio source, we considered it the most likely optical component. This algorithm is easily formalized and gives a confident result if the morphology of the radio source is close to classical. In more complex cases, we used the ALADIN software (Bonnarel et al., 2000) to visually verify the identification.

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2. OBSERVATIONS

The spectroscopic observations of the host galaxies were carried out at the 6-m BTA telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences with a multi-mode device SCORPIO-2 (Afanasiev & Moiseev, 2011) as an auxiliary program when the weather conditions prevented the implementation of the main program. The observations were made in the long-slit spectroscopy mode, with the VPHG940@600 grism providing the spectral range of 3700–8500 Å with the resolution of about 7 Å at the slit width of 1″.

The data reduction was carried out by the authors' software running in the `IDL` environment. The toolkit performs conventional procedures in the present sequence: bias and flat-field correction, wavelength calibration, flux calibration using the spectra of the spectrophotometric standard stars observed in the same night. To extract the spectrum of the studied object with the maximum signal-to-noise ratio, the 2D-spectrum was convoluted with the weighted average cross-dispersion profile of the standard star spectrum. The log of observations is given in Table 1.

Table 1. Log of observations

Object name	Date of observations	Exposure, s
0422+1510	20/21.02.2012	600 × 2
0422+1407	21/22.02.2012	900 × 2
0638+3334	21/22.02.2012	900 × 2
1427+2657	12/13.05.2013	600 × 1
1240+5330	12/13.05.2013	600 × 1
1421+1016	14/15.06.2013	600 × 1
1301+5408	14/15.06.2013	600 × 2
1600+6137	14/15.06.2013	300 × 2
0003+0351	06/07.11.2013	300 × 3

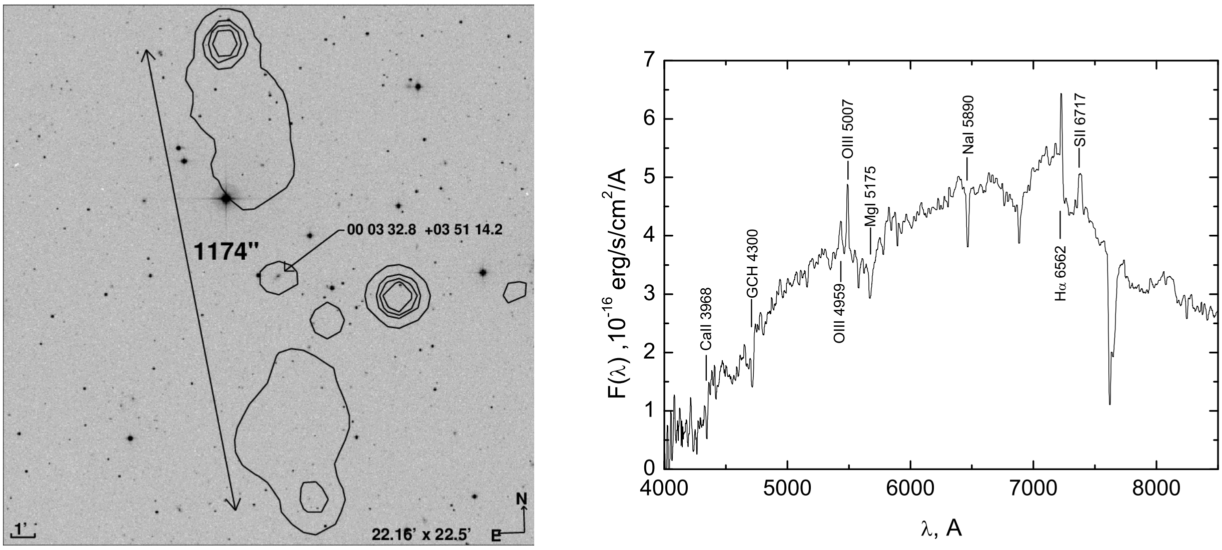

Fig. 1. The radio source 0003+0351. Left plot: the contours of the NVSS radio map, superimposed onto the image from the DSS2-red. The arrow marks the position of the host galaxy and its optical coordinates, the accepted size of the radio structure is also denoted. Right plot: the optical spectrum of the host galaxy: the positions of the main emission and absorption lines are marked.

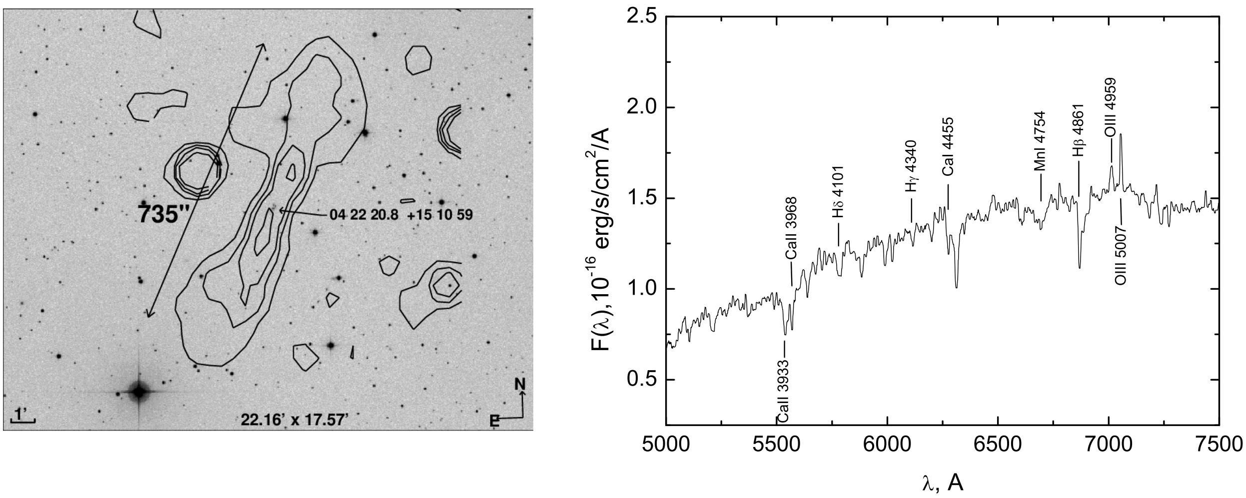

Fig. 2. Similar to Fig. 1 for the source 0422+1512.

3. RESULTS

Table 2 lists the observed radio sources and their parameters: (1) the name of the object; (2, 3) the coordinates of the radio source centroid; (4) the apparent angular size, measured as the angular distance between the most distant components of the radio source; (5) the integral flux at the frequency of 1.4 GHz; (6) redshift; (7) the linear size within the ΛCDM standard cosmological model.

Figures 1–9 present the NVSS and/or FIRST maps of radio sources, combined with the DSS2-red images. The maps show the angular size of the radio source (the long arrow parallel to the major axis of the radio source), position and coordinates of the host galaxy. The right-hand side plots demonstrate the spectra of the optical components of radio sources.

The field of the 1600+6137 source captured two galaxies separated by 28″ (54 kpc in projection). The spectrograph slit passes through both objects. The resulting spectra are very similar, what is not surprising for the elliptical galaxies similar in size and luminosity. The radial velocity difference of these galaxies is about 200–300 $\mathrm{km\,s^{-1}}$; they most likely form a physical pair. The radio images of these objects with high angular resolution from the FIRST survey are shown in Fig. 9 by the white contours. Since the angular resolution of the NVSS and FIRST is 45″ and 5″, respectively, faint extended regions detected by the NVSS are not visible in the FIRST. At the same time, the activity of these objects in the radio range according to the FIRST is one and a half order: the flux at 1.4 GHz from the Northern galaxy at the 77.5 mJy, while it is 2.63 mJy for the Southern galaxy. The big difference between the

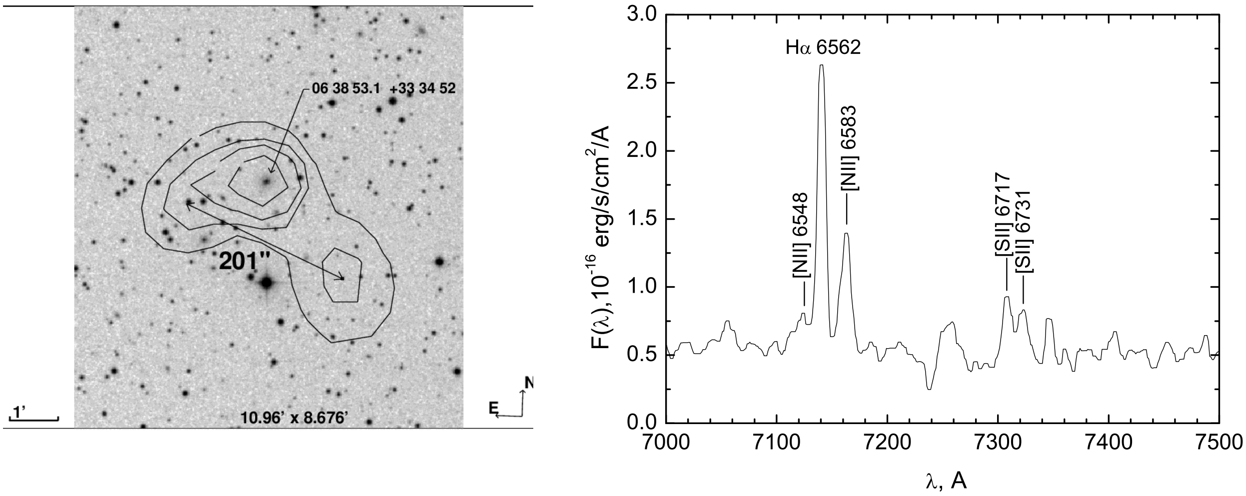

Fig. 3. Similar to Fig. 1 for the source 0638+3334.

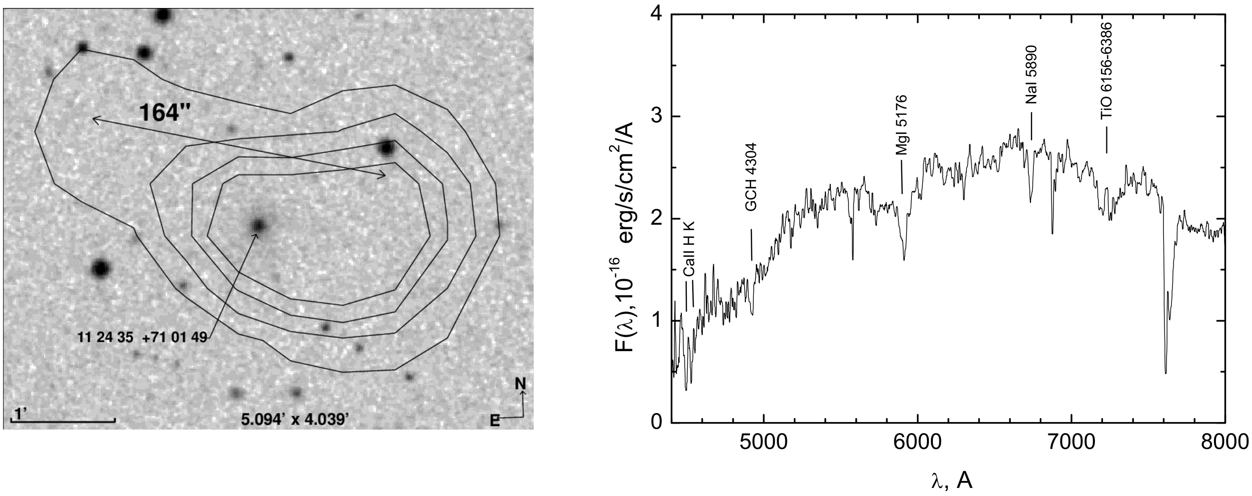

Fig. 4. Similar to Fig. 1 for the source 1124+7102.

Table 2. The radio source parameters

Object name	RA 2000.0	DEC 2000.0	Θ, arcsec	S, mJy	z	D, Mpc
(1)	(2)	(3)	(4)	(5)	(6)	(7)
0003+0351	00 03 32.83	+03 51 14.2	1174	450.8	0.097	2.08
0422+1512	04 22 18.53	+15 12 39.3	735	168.8	0.409	3.98
0638+3334	06 38 52.79	+33 34 08.1	201	268.7	0.088	0.33
1124+7102	11 24 35.89	+71 02 08.5	164	83.3	0.141	0.40
1240+5334	12 40 13.66	+53 34 38.5	156	276.8	0.293	0.68
1301+5408	13 01 38.00	+54 08 21.4	131	276.4	0.336	0.62
1421+1016	14 21 43.30	+10 16 25.0	135	238.8	0.370	0.69
1427+2657	14 27 34.10	+26 57 11.2	101	45.3	0.170	0.29
1600+6137	16 00 28.17	+61 37 17.3	180	129.7	0.114	0.35

fluxes might be due to the anisotropy of the radiation in the radio range and different spatial orientations of the radio source structures.

Table 2 contains the measured redshifts and calculated apparent sizes of the observed radio sources. The calculations assumed $\Omega_m = 0.27$, $\Omega_v = 0.73$, H_0 =71 km s^{-1} Mpc^{-1}. Two objects from our list got past the conditional boundary of 1 Mpc and hence make it to the list of giants. The most extended object of the sample, 0422+1512 is only a little smaller than the longest known radio source 3C 236. Machalski et al. (2001) give the physical size of this object, 5.65 Mpc, assuming the Friedmann cosmology with the Hubble constant of $H = 50$ km s^{-1} Mpc^{-1} and the deceleration

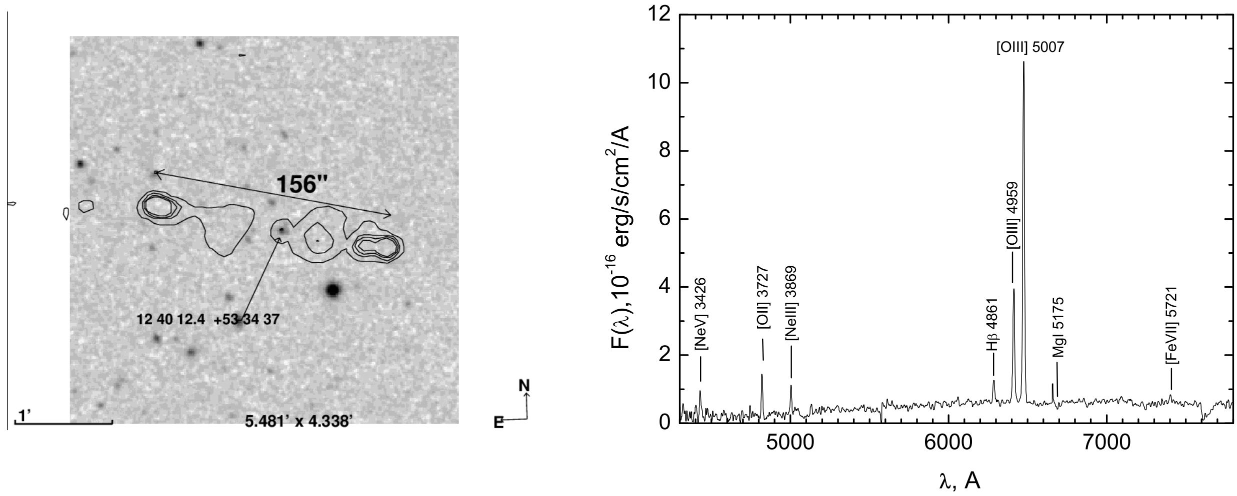

Fig. 5. The FIRST map contours. The rest is similar to Fig. 1 for the source 1240+5334.

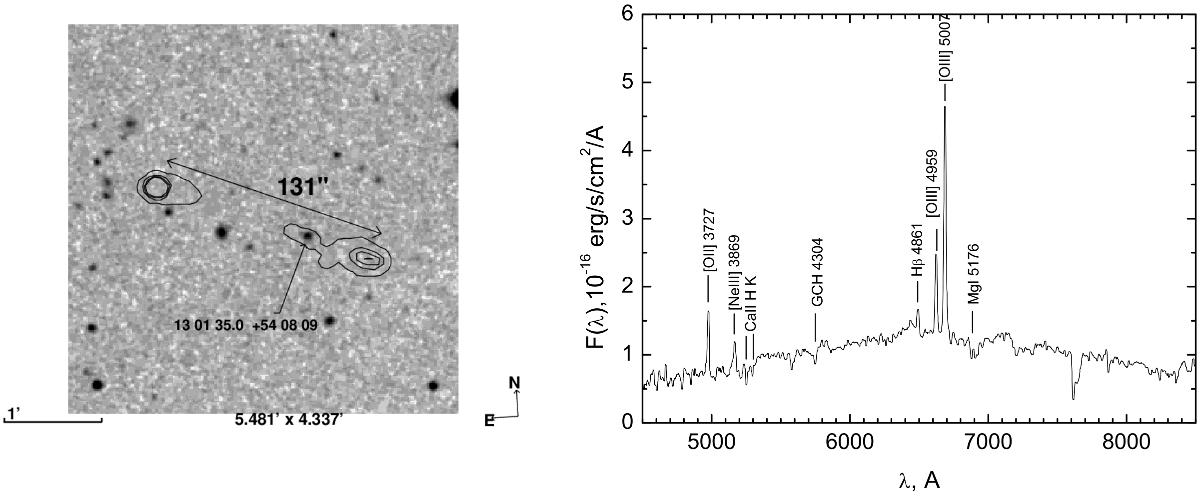

Fig. 6. Similar to Fig. 5 for the source 1301+5408.

parameter $q_0 = 0.5$. In the current model, given the angular size of 3C 236 of around 2300″, its physical size is 4.15 Mpc, which is practically the same as that of 0422+1512.

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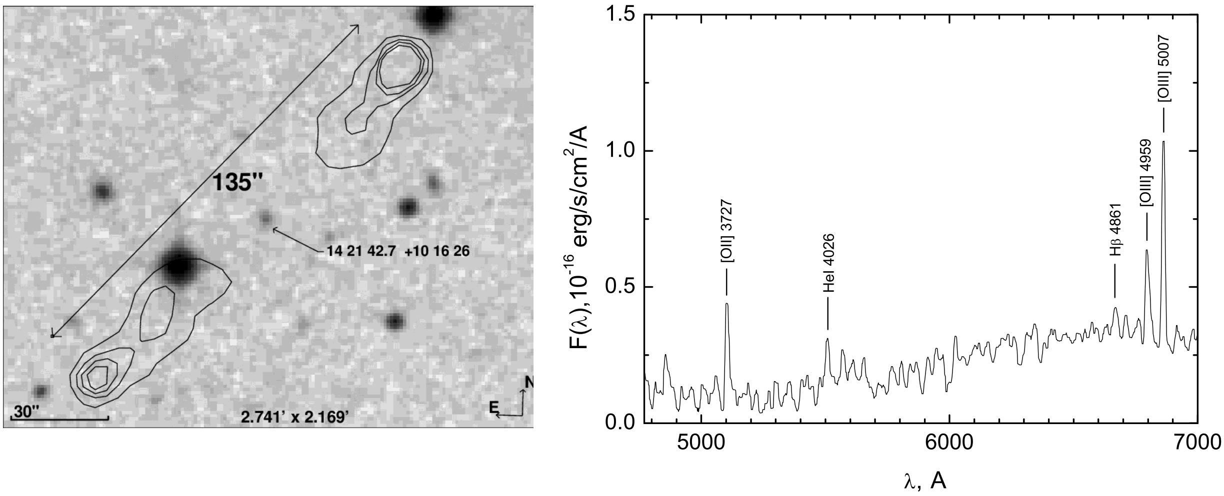

Fig. 7. Similar to Fig. 5 for the source 1421+1016.

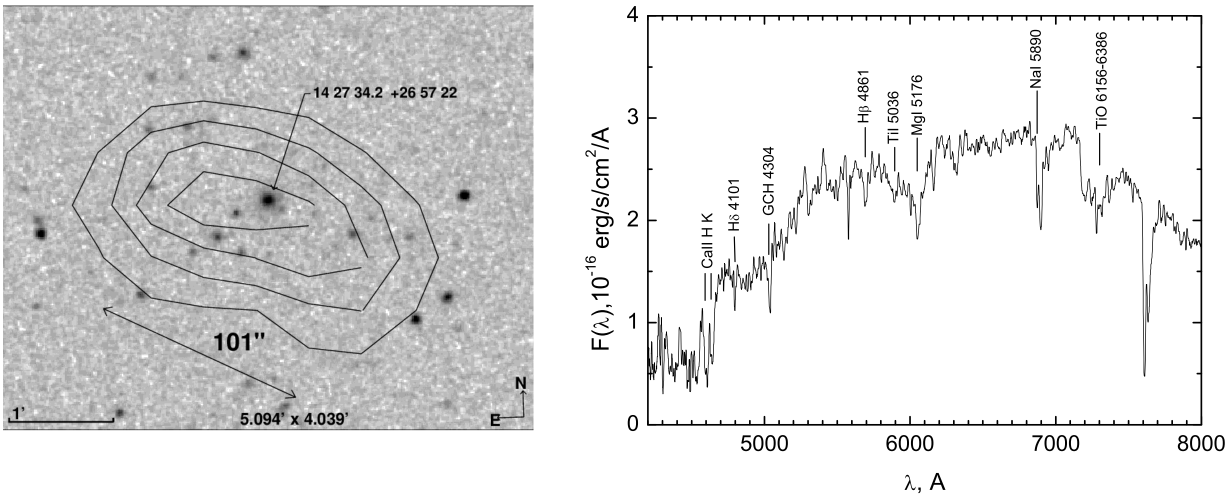

Fig. 8. Similar to Fig. 1 for the source 1427+2657.

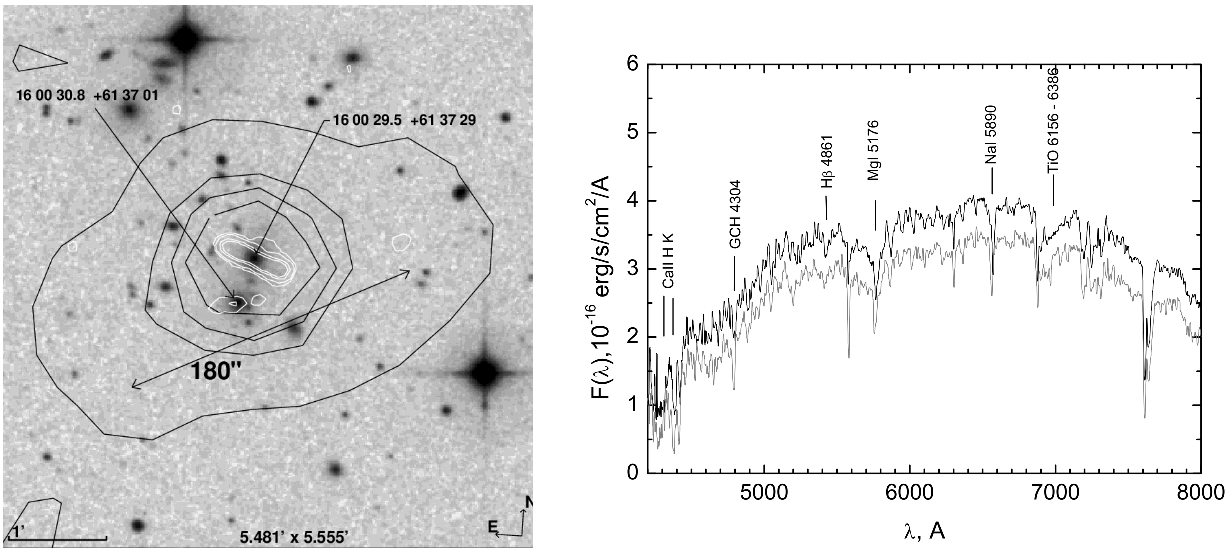

Fig. 9. Similar to Fig. 1 for the source 1600+6137. White inner contours denote the FIRST data, the outer contours—the NVSS data. The spectra of both galaxies are shown. To distinguish between the spectra, the spectrum of the Nothern galaxy is shifted upward along the vertical axis.